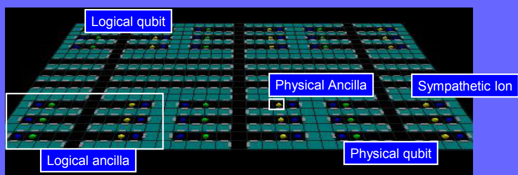
Progress towards Planar Ion Traps for Quantum Computation

Ken Brown, W. Bakr, R. Clark, J. Labaziewicz, D. Leibrandt, C. Pearson, I. Chuang

Department of Physics, Research Laboratory of Electronics, and Center for Bits and Atoms, MIT, Cambridge, MA 02139 USA

Ion Trap Quantum Computation

Trapped ions have been used to perform a wide range of basic quantum protocols on a small number of qubits. However, the task of building an ion trap system that allows one to manipulate hundreds of qubits remains quite challenging. A promising proposal for building large scale ion trap quantum computers is to shuttle ions between gate locations in a multi-zoned RF trap[1]. When the proposal is combined with the demands of fault-tolerant quantum error correction, the result is a geometrically complex trap design.[2]



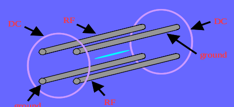
[1] D. Kielpinski, C.R. Monroe, and D.J. Wineland, Nature **417** 709 (2002)

[2] A.W. Cross, Master's thesis, "Synthesis and Evaluation of Fault Tolerant Architectures", (2005)

Acknowledgements: DARPA

Multi-zone ion traps

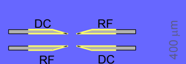
- Linear 4-rod trap



A single zone ion trap is a quadrupole mass filter with confinement along the axis provided by DC bias on the endcaps.

- Segmented 4 electrode trap

M. D. Barrett et al. Nature 429 737 (2004)

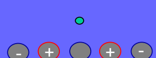


By segmenting the DC rod, one can define different trapping zones. Ions can then be coherently shuttled from zone to zone.

- Planar 5 electrode trap

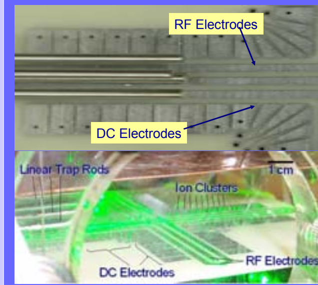
J. Chiaverini et al. quant-ph/0501147

S. Seidelin et. al. quant-ph/0601173



All the electrodes are on the same plane and the ion is trapped above the surface. For similar dimensions and RF voltages, planar traps have a smaller trap depth and larger surface area compared to four-rod traps. This leads to challenges for ion loading, ion motion, and ion heating.

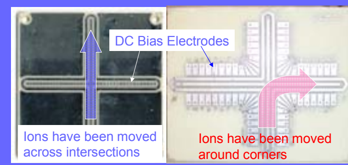
Ion Loading and Ion Motion In Planar Traps



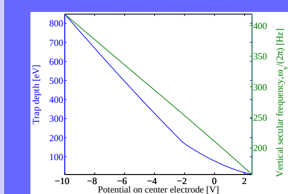
One way to efficiently load macroscopic ions into planar traps is to first load into a 4-rod trap and then offload onto the planar trap. Ions were detected by the observation of non-resonant laser scatter.

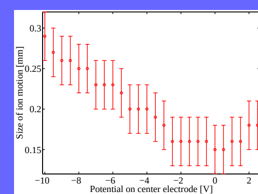
By biasing the DC electrodes, it is possible to shuttle the ions from zone to zone. We have moved ions around corners and through four-way intersections.

C. E. Pearson et. al., quant-ph/0511018

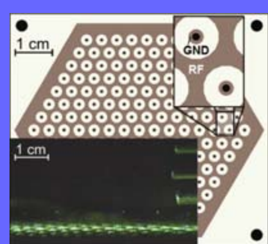


Bias control was made more efficient by segmenting the inner instead of the outer DC electrode.





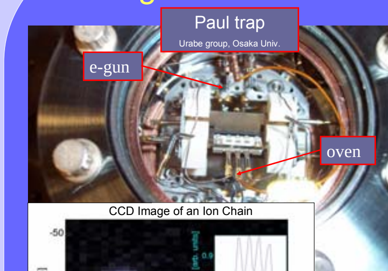
We have found that we are able to increase the trap depth of planar ion traps by adding either a positive DC potential to a planar electrode parallel to and above the surface of the trap or a negative DC potential to the center electrode. This configuration moves the ion off of the RF null and leads to increased micromotion, so it can be used only while loading.



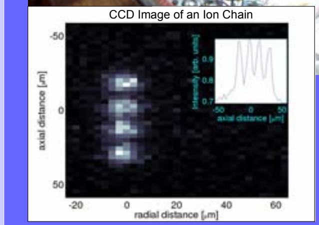
We have also trapped macroscopic ions in a hexagonal lattice of point traps made by placing an array of DC electrodes in a plane of RF voltage. Atomic ions trapped in such a configuration with a lattice spacing of about 50um could be used to study interesting phase transitions in condensed matter systems.

Acknowledgements: Tongyan Lin and ARDA

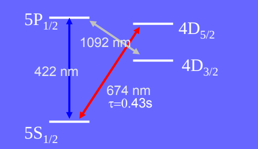
Progress towards Heating Rates



To measure heating rates, laser cooled atomic ions are necessary. We have loaded Sr^+ ions using electron impact ionization of neutral Sr vapor, in a conventional linear Paul trap.



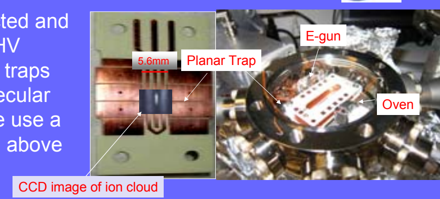
We have laser cooled and imaged single ions in our linear trap. The ions are spaced ~12μm apart.



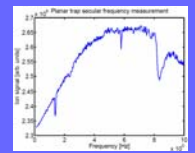
The cooling (422nm), repumping (1092nm), and clock transition (674nm) lasers have been made from laser diodes in a compact monolithic design with optical feedback stabilization. The 674nm laser will be used to measure heating rates by probing the motional sidebands.

Acknowledgements: Urabe, Osaka Univ.; Hayasaka, NICT; and JST/CREST

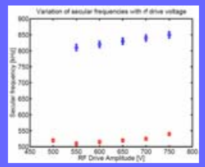
We have constructed and trapped ions in UHV compatible planar traps based on the molecular cluster design. We use a positive bias 6mm above the trap surface.



Initial experiments in this trap have included measuring the secular frequencies as a function of the top plate voltage and rf voltage.



Resonances occur at the secular frequencies when a small rf voltage is applied to nearby electrodes.



As expected, the radial frequency (blue) decreases faster than the vertical frequency (red) as the rf amplitude is lowered. A quantitative model of the trap for predicting these frequencies is in preparation.

Acknowledgements: Phil Richerme